

# **Estimated versus perceived damage control productivity: Impact of birds on irrigated rice in the Senegal River Valley**

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## **Abstract**

Granivorous birds, mainly the Red-billed Quelea, have subsisted on cereal crops in Africa for centuries and have caused substantial damage to agriculture. Limited recent evidence is available however on the impact of birds on cereals in Africa. In order to estimate bird-inflicted crop losses in rice production, we fit a production function with fixed effects and a damage abatement component with pest intensity slope dummies on a panel database of irrigated rice farmers in the Senegal River Valley. This specification enables estimating bird damage, averaging around 11.2% of the potential rice yield during the wet seasons of 2003-2007. This translates into an average annual economic loss of 4 billion FCFA (€6.2 million) for the irrigated rice sector in the Senegal River Valley. However, losses can amount to 9.2 billion FCFA (€14.1 million) in years with extremely high bird pressure, such as in 2006. In comparison, farmers perceive bird damage to be on average 15.2% of the potential rice yield. Both the estimated and perceived damage abatement productivity levels indicate that at high bird pressure, the efficacy of traditional bird scaring methods is inadequate. These findings highlight the need for developing enhanced bird control techniques and provide timely information for policy makers who are currently implementing an ambitious food self-sufficiency program in Senegal.

## Introduction

Senegal is a country highly dependent on food imports, especially for rice as it only covered 28% of domestic rice demand in 2008 (Gergely and Baris, 2009). It is the second largest rice importer in sub-Saharan Africa and ranks tenth in the world (Brüntrup *et al.*, 2006). This heavy reliance on imported rice not only puts a major burden on the country's trade and foreign exchange balance, but also explains why Senegal was hit very hard by the recent food crisis. The Senegalese government now attaches high priority to the development of its local rice sector because it provides national food security, supports economic growth and alleviates poverty. In April 2008, the Senegalese government launched the GOANA (Grand Offensive in Agriculture for Food and Abundance) program with the ambitious goal of achieving self-sufficiency by the year 2015 (Ministère de l'Agriculture et de l'Elevage, 2008). Concerning rice, the program aims at increasing domestic production from 200,000 tons to at least 500,000 tons by 2015. Most attention goes to increasing production through massive investments in existing and new rice perimeters. However, to increase productivity in this sector, the main production constraints in irrigated rice also need to be tackled.

There are many constraints to the cultivation of irrigated rice such as: poor land preparation, bad irrigation management, inadequate drainage leading to the development of salinity and alkalinity, inefficient distribution of inputs and yield instability due to weeds, insects and diseases (Balasubramanian *et al.*, 2007). Focusing on the Senegal River Valley (SRV), weeds and birds are regarded as the two most important pests in irrigated rice production. Although birds are mentioned as a constraint of irrigated rice production in many publications (e.g. Ezealor and Giles, 1997; Le Gal and Papy, 1998; Poussin *et al.*, 2003; Vick, 2006; Connor *et al.*, 2008; Demont *et al.*, 2009; Rodenburg and Johnson, 2009) and objective studies measuring loss levels exist (e.g. Bruggers and Ruelle, 1981), no recent study exclusively focuses on birds as a pest to irrigated rice production in sub-Saharan Africa. Up to

date bird damage estimates are also lacking. This lack of recent published evidence was found to be in contrast to the increasing importance of bird damage as revealed by our annual farmer surveys conducted in the SRV since 2002. In order to put the bird problem into perspective and provide a functional foundation for future research and control strategies, accurate figures of bird-inflicted crop losses despite actual bird control strategies are needed. These figures also provide useful information for farm management decision making and the allocation of research funding at the governmental level. Therefore, this study contributes to the productivity and damage abatement literature by presenting and comparing both econometric estimates and farmer perceptions of the impact of birds on irrigated rice production in the SRV.

### **Damage inflicted by pest birds in cereal crops in Africa**

Bird problems in agriculture have existed since the foundation of agriculture (Wright, 1980). Still today, there are countless bird problems around the world, which vary greatly in importance, costs involved and responsible species. Some examples of bird problems include: (i) bird hazard to aircrafts, (ii) predation on desired species, (iii) urban and rural roost problems, (iv) birds as carriers or transmitters of diseases and (v) damage to agricultural production (De Grazio, 1978).

Focusing on bird species that cause damage on cereal crops in Africa, the most important species include the Red-billed Quelea (*Quelea quelea*), the Golden Sparrow (*Passer luteus*), the Village Weaver (*Ploceus cucullatus*) and the Glossy Starling (*Lamprotornis chalybaeus*) (FAO, 1991). The main pest species in the SRV are generally ploceid weavers, particularly the Red-billed Quelea and the Golden Sparrow (Bruggers and Ruelle, 1981 and Ibrahima Diop, chief of DPV Saint-Louis, personal communication). The Red-billed Quelea is one of the most notorious pest bird species in the world. It occurs in sub-Saharan Africa where it gathers in vast flocks of several million birds and breeds in

gregarious colonies which can cover more than 100 hectares (with about 30,000 nests per hectare). It is considered the most numerous bird worldwide with population numbers totaling about 1.500 million at the end of the breeding season (Elliott, 1989). Its staple diet consists of wild annual grasses, yet when this natural source becomes scarce during the dry season, cultivated cereals become their alternative food source. Until present day, the Red-billed Quelea has received a serious amount of study and there are many publications describing its pest status and control strategies in African agriculture (see: Bibliography of the African quelea species, Oschadleus, 2001). The golden sparrow is mainly responsible for damage to ripening sorghum and to a lesser extent to irrigated rice and millet (Bruggers and Ruelle, 1981). Just like the Red-billed Quelea, its staple diet consists of seeds of wild grasses. It can be found in smaller groups of around 150 to 200 individuals and its roosting sites are far less dense with around 30 to 50 nests per hectare (Sidibé *et al.*, 2003).

Birds are a rather specific pest species on cereal crops in Africa due to the fact that they can migrate over long distances, occur in great numbers and have a flexible diet, in which agricultural crops may only feature an incidental role. Hence, a great variability exists in the extent of the damage farmers experience because there are many factors that influence the occurrence and intensity of bird damage. Examples of these factors include field properties (e.g. field size), agronomic properties (e.g. timing of production) and environmental properties (e.g. climate).

Bird damage to agricultural crops can be substantial in many parts of the world and many studies quantifying these losses exist. Global data or aggregate studies, however, are scarce. The latest extensive overview of world bird damage problems has been provided by De Grazio (1978); a more recent overview is lacking in the literature. Focusing on bird damage on cereal crops in Africa, Table 1 provides a non-exhaustive literature overview. The presented bird damage estimates vary greatly between countries and even within countries

large region wise differences are reported. In general, these studies point out that bird damage is an important loss factor and that birds inflict substantial economic damage. The main pest species mentioned are the Red-billed Quelea, although others were also mentioned. This table further illustrates that recent peer-reviewed evidence is lacking. The single most recent study was conducted by Sidibé *et al.* (2003) in which proportionate damage on irrigated rice in Mali was estimated at 22% of production using a questionnaire survey.

Regarding the SRV, to our knowledge the most reliable estimate was given by Bruggers and Ruelle (1981), who estimated bird damage on irrigated rice at 6.8% of production between 1976 and 1977. The most recent estimate was given by the head of the Saint-Louis division of the governmental Crop Protection Directorate (DPV) that is responsible for bird control. The DPV estimates bird damage in the order of 15% of regional production; this estimate should be treated with reserve, however, since no clear scientific methodology was described. As a conclusion, Table 1 suggests an order of magnitude for bird damage of about 15-20% of production. Large differences between production seasons and farmers can occur, however, due to the high temporal and spatial heterogeneity of the bird problem.

< INSERT TABLE 1 HERE >

## **Material and methods**

Many direct techniques exist to assess crop losses inflicted by birds. Usually, these techniques involve weighing, counting and visual estimation of the inflicted damage. However, due to the heterogeneity of the bird problem, for these methods to be representative, a large sample size is needed across several production seasons which renders this method labor intensive and expensive. Indirect methods include questionnaire surveys and energetic models that use estimates of bird population sizes to predict the amount of damage the pest population will inflict.

This study uses two indirect approaches to estimate bird damage, i.e. (i) by using a damage abatement (DA) production function approach on a panel dataset of farmers, and (ii) by surveying farmers' perceived losses inflicted by birds. The DA production function approach and corresponding DA literature will be elaborated below, details regarding the questionnaire survey can be found in the data section.

The DA literature arose from publications about pesticide productivity and has mainly focused on the correct specification of the production function. In the traditional production function specification,  $Y = f(\mathbf{X})$ , all inputs  $\mathbf{X}$  are treated symmetrically, i.e. they are assumed to contribute to production in the same way. Lichtenberg and Zilberman (1986) criticized this specification by proposing an asymmetrical specification that treats productive inputs  $\mathbf{X}$  and damage abating inputs  $\mathbf{Z}$  differently. Their rationale behind this is that damage abating inputs are not standard factors of production that directly increase yield, but are damage control agents which indirectly mitigate yield loss through the elimination of pests. They define a specific function  $g(\mathbf{Z})$ , the damage abatement function, to describe the DA inputs' specific role in production:  $Y = f(\mathbf{X}, g(\mathbf{Z}))$ . The DA function represents the percentage of damage that is eliminated by the use of the DA inputs  $\mathbf{Z}$  and possesses the properties of a cumulative probability distribution: it is defined on the interval  $[0,1]$  with  $g = 0$  meaning zero elimination of damage,  $g = 1$  denoting complete eradication of damage, it is a monotonically increasing function and  $g(\mathbf{Z}) \rightarrow 1$  when  $\mathbf{Z} \rightarrow \infty$ . A simple linear form of the asymmetric specification is  $Y = f_1(\mathbf{X}) + f_2(\mathbf{X})g(\mathbf{Z})$ , where  $f_1(\mathbf{X})$  represents minimal output and  $f_2(\mathbf{X})$  potential output on which  $g(\mathbf{Z})$  works as a scaling factor. Choosing minimal output equal to zero, this equation is reduced to  $Y = f(\mathbf{X})g(\mathbf{Z})$ . This equation symbolizes that the DA production function approach is based on the damage abatement process that is multiplicatively separable from the production process: the DA function  $g(\mathbf{Z})$ , representing the percentage of prevented damage, influences potential yield  $f(\mathbf{X})$  as a scaling factor. Following its definition, one minus

the DA function represents the pest-inflicted loss function at various pest control levels. Thus by estimating a production function with an embedded DA function, farm level bird damage estimates can be obtained by feeding the loss function with observed pest control levels. Note that the DA function uses bird control efforts as an input to represent the abatement process; hence this approach uses bird control as a proxy to estimate bird damage.

The damage abatement specification proposed by Lichtenberg and Zilberman (LZ) was successfully applied by Babcock *et al.* (1992), Carrasco-Tauber and Moffitt (1992), Chambers and Lichtenberg (1994), Saha *et al.* (1997), Huang *et al.* (2002), Norwood and Marra (2003), Qaim (2003) and Shankar and Thirtle (2005). This output oriented damage abatement specification (i.e. DA inputs reduce the loss inflicted on potential output) was questioned however by Carpentier and Weaver (1997), who proposed an input damage abatement specification which was further elaborated by Oude Lansink and Carpentier (2001). The input damage abatement specification is a more general treatment and is based on the principle that DA inputs have an impact on the productivity of productive inputs. Zhengfei *et al.* (2005) expanded the DA literature further by proposing an input damage abatement specification that allows marginal products of pesticides to be negative (these were presumed to be positive a priori in previous literature) and allows inputs to be both damage abating and yield increasing. One year later, Zhengfei *et al.* (2006) broadened this DA framework by presenting a new dichotomous paradigm based on agronomic insights that categorizes inputs into growth- and facilitating inputs. Kuosmanen, Pemsler and Wesseler (2006) step aside from the standard production function approach to estimate the productivity of damage control inputs and employ a two-stage semi parametric technique to estimate the productivity of damage control inputs. This approach combines the attractive features of both nonparametric features (e.g. no need for assumptions about functional forms and parameter restrictions) and parametric features (e.g. the ability to summarize productivities into a single coefficient). In

this specification, they specify damage agent variables as slope dummies, which they show to have a major impact on the effectiveness of the DA inputs they considered. Despite the recent development of the input DA approach in the literature, an output DA approach can still be meaningful however when an input DA approach is not preferable due to its high level of non-linearity and the related estimation problems.

Aside from the specification of the input DA approach, the DA literature also further expanded the original LZ model. Fox and Weersink (1995) demonstrate that the choice of functional form of the DA function is very important. Carpentier and Weaver (1997) conclude that the inclusion of fixed effects in the DA model is crucial to capture spatial and temporal heterogeneity in the data. Norwood and Marra (2003) argue that pest pressure information needs to be included in the production function analysis and that in absence of this information, marginal products of pesticides will probably be underestimated. Concerning the choice of the functional form of the production function, a flexible function is preferred over the inflexible Cobb-Douglas (Oude Lansink and Carpentier, 2001). These findings from the literature were taken into account upon specifying the model below.

### *Model specification*

Many functional forms for production functions are possible. In the literature, flexible functional forms such as the translog, leontief or quadratic production functions are preferred because they do not put too much restrictions across effects and have sufficient parameters to represent comparative statics at a point (Anderson *et al.*, 1996). This study adopts the traditional Cobb-Douglas (CD) specification however due to its ease of estimation and because flexible forms require many observations due to the large amount of model parameters, which reduces the degrees of freedom of the model substantially. Due to the panel structure of the dataset, fixed farm and time effects were included in the production function;



their inclusion was concluded to be essential by Carpentier and Weaver (1997). The mathematical specification of the loglinear form of the production function is:

$$\ln(Y) = \alpha + \sum_{i=1}^5 \beta_i \ln(X_i) + \ln(G(Z_j)) + \sum_{k=1}^{110} f_k + \sum_{m=1}^4 t_m + \varepsilon \quad (1)$$

where  $\alpha$ ,  $\beta_i$ ,  $f_k$  and  $t_m$  are parameters to be estimated. The arguments  $X_i$  are the productive inputs, with  $i = 1$  (land), 2 (seed), 3 (labor), 4 (fertilizer), 5 (irrigation costs). Farm effects are captured by the farm dummy  $f_k$  and year effects by the time dummy  $t_m$ . The term  $G(Z_j)$  represents the DA functions for weeding and bird control and will be specified below. The error term is depicted as  $\varepsilon$  and captures all stochastic events that are not accounted for in the specification.

Many different specifications for the DA function have been tested in the literature. Because there are two independent sources of damage in this study, i.e. weed and bird damage, two multiplicatively separable DA functions were included in the production function analogous to Babcock *et al.* (1992). The Weibull specification was adopted for the bird DA function and the exponential specification for the weed DA function. These specifications were chosen amongst others because of their computational tractability and satisfactory fit to the data.<sup>1</sup> The mathematical representation of the DA functions' specification is:

$$G(Z_j) = [1 - \exp(-\gamma_w Z_w)][1 - \exp(-Z_b^{\gamma_b})] \quad (2)$$

where  $Z_w$  and  $Z_b$  represent weeding efforts and bird control respectively and  $\gamma_w$  and  $\gamma_b$  are parameters to be estimated.

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<sup>1</sup> Other functional forms such as the logistic specification were also tested but provided poor results for our data or resulted in non-converging models.

One feature discussed in the DA literature is the inclusion of pest pressure information, which has been shown to have an important influence by Norwood and Marra (2003). We therefore modeled bird pressure information using slope dummies analogous to Kuosmanen *et al.* (2006) which transforms equation (2) into:

$$G(Z_j) = [1 - \exp(-\gamma_w Z_w)] \left[ 1 - \exp(-Z_b \gamma_b^L) \right]^{\delta_L} \left[ 1 - \exp(-Z_b \gamma_b^M) \right]^{\delta_M} \left[ 1 - \exp(-Z_b \gamma_b^H) \right]^{\delta_H} \quad (3)$$

where  $\delta_L$ ,  $\delta_M$  and  $\delta_H$  are respectively low, medium and high bird pressure dummies and  $\gamma_b^L$ ,  $\gamma_b^M$  and  $\gamma_b^H$  are the corresponding DA function parameters. This specification allows us to evaluate the bird control efforts according to different pest pressure levels. Note that the bird pressure dummy for ‘no birds’ is not present in this specification because in that case the DA process is nonexistent.

With the production function and the damage abatement function defined, we obtain the final model specification by substituting equation (3) into equation (1):

$$\begin{aligned} \ln(Y) = & \alpha + \sum_{i=1}^5 \beta_i \ln(X_i) + \ln[1 - \exp(-\gamma_w Z_w)] \\ & + \delta_L \ln \left[ 1 - \exp(-Z_b \gamma_b^L) \right] + \delta_M \ln \left[ 1 - \exp(-Z_b \gamma_b^M) \right] \\ & + \delta_H \ln \left[ 1 - \exp(-Z_b \gamma_b^H) \right] + \sum_{k=1}^{110} f_k + \sum_{m=1}^4 t_m + \varepsilon \end{aligned} \quad (4)$$

This model will be referred to as the DA-I (Damage Abatement with pest Intensity dummies) model henceforward.

In this study, the DA-I model will be compared to three other models. This comparison is aimed at investigating the difference (i) between the traditional Cobb-Douglas specification of the production function that treats all inputs symmetrically and the

asymmetric DA specification and (ii) between the omission and inclusion of pest pressure information. Regarding to (i), the traditional production function model can be expressed as:

$$\ln(Y) = \alpha + \sum_{i=1}^5 \beta_i \ln(X_i) + \sum_{j=w,b} \gamma_j \ln(Z_j) + \sum_{k=1}^{110} f_k + \sum_{m=1}^4 t_m + \varepsilon \quad (5)$$

This model will be referred to as the CD (Cobb-Douglas) model. This linear model can be further expanded by including bird intensity dummies:

$$\begin{aligned} \ln(Y) = \alpha + \sum_{i=1}^5 \beta_i \ln(X_i) + \gamma_w \ln(Z_w) + \delta_L \gamma_b^L \ln(Z_b) + \delta_M \gamma_b^M \ln(Z_b) \\ + \delta_H \gamma_b^H \ln(Z_b) + \sum_{k=1}^{110} f_k + \sum_{m=1}^4 t_m + \varepsilon \end{aligned} \quad (6)$$

This model will be referred to as the CD-I (Cobb-Douglas with pest Intensity dummies) model.

To fully explore the difference between using pest intensity dummies or not, the final model to be specified is the DA (Damage Abatement) model, which is the asymmetric DA-I model without the bird intensity dummies:

$$\begin{aligned} \ln(Y) = \alpha + \sum_{i=1}^5 \beta_i \ln(X_i) + \ln[1 - \exp(-\gamma_w Z_w)] + \ln[1 - \exp(-Z_b^{\gamma_b})] \\ + \sum_{k=1}^{110} f_k + \sum_{m=1}^4 t_m + \varepsilon \end{aligned} \quad (7)$$

### *Estimation*

The CD and CD-I models are both fixed-effects loglinear models which can be estimated straightforward using Ordinary Least Square (OLS) estimation. The nonlinear DA and DA-I models on the other hand require use of the Nonlinear Least Square (NLS) estimator (Greene, 2003: p. 166-169). This estimation method is based on the linearized regression model derived from the first-order Taylor series approximation. The method works iteratively: the

pseudo-regressors in the linearized model are evaluated at certain starting values and the linearized model is estimated using linear least squares; the obtained vector serves as new starting values to compute the pseudo-regressors; this procedure is repeated until the parameter vector converges. The statistical inference of the NLS estimator is based on asymptotic approximations, which means that no particular distributions are required and no normality is assumed for the error term  $\varepsilon$ , which makes the comparison between the linear and nonlinear models consistent. Both the linear and nonlinear models were estimated using the statistical software package R for Mac (R Development Core Team, 2008).

## **Data**

### *Panel dataset*

Since 2002, the Africa Rice Center annually surveys a representative stratified random sample of irrigated rice farmers in the SRV. We use the 2003-2007 panel dataset with a sample size of 111 unique farmers totaling 473 farmer $\times$ season observations. The panel is unbalanced, most farms were surveyed in the sample for the entire five year period; some farmers were replaced by others. The data is only for the wet season production, which is the main production season in the SRV: for the period 1965-2005 the mean yearly acreage during the wet season amounted to six fold the dry season production (SAED/DDAR/CSE, 2007). The SRV is divided into three zones: the Delta, the Middle Valley and the Upper Valley. The panel covers the first two zones, which is considered as a good representation since both zones together represent 89% of irrigated rice production in the SRV (SAED/DDAR/CSE, 2007).

One output and seven inputs were distinguished. The output consists of paddy rice production expressed in tons. The inputs were classified as productive inputs and damage abating inputs. The former include land, seed, labor, fertilizer and irrigation costs; the latter

include weeding efforts and bird control. Land represents the amount of land a farmer used during the production season and is measured in hectare. Seed is the total amount of seed used and is expressed in kilogram. Labor includes both family and externally hired labor, which were assumed to be equally productive, and is expressed in man×days. The labor spent on manual weeding and bird scaring is not included in this variable. Fertilizer is the total amount of fertilizer used and is measured in kilogram. Irrigation costs represent the size related fixed fee farmers have to pay to the irrigation scheme union and are expressed in FCFA. The variable weeding efforts aggregates herbicide expenditures and manual labor costs spent on weeding and is expressed in FCFA.<sup>2</sup> Bird control is total bird scaring efforts in man×days. For the variables weeding efforts and bird control, zero values were replaced by unity, as is commonly done in the DA literature, to circumvent errors when taking the natural logarithm of these variables in the models, i.e. it assumes that  $\ln(0) = \ln(1) = 0$  for the critical observations. The variables irrigation costs and weeding efforts which are expressed in value were not deflated given the quasi constant prices of these inputs during the considered period.

The bird pressure dummies were obtained from a second survey which will be described below. We distinguish four dummies, i.e. (i) no birds, (ii) low bird intensity, (iii) medium bird intensity and (iv) high bird intensity. Descriptive statistics of all variables can be found in Table 2.

< INSERT TABLE 2 HERE >

### *Complementary survey*

To obtain bird damage perceptions and further understand farmers' perceptions regarding the bird problem in the SRV, a survey complementary to the aforementioned annual panel

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<sup>2</sup> One man×day of manual weeding was valued at 731 FCFA. This is based on a wage of 19,000 FCFA/month (the standard wage paid for unskilled labor in the region) divided by 26 working days per month.

surveys was conducted amongst the same sample of 111 farmers. The survey contained two large parts, i.e. (i) a year-by-year recall questionnaire for the period 2003-2007 that was aimed at further understanding the bird (control) problems during each year of the panel used in the production function analysis and (ii) a general questionnaire on bird control practices in the SRV. The results from the first part will be discussed in the next section, the results of the second part will not be fully elaborated but some key findings will be presented throughout this paper.

The survey was conducted with the aid of the extension organization SAED (*Société d'Aménagement et d'Exploitation des terres du Delta et des vallées du fleuve Sénégal et de la Falémé*). Twelve SAED interviewers responsible for their own village contacted the panel farmers, interviewed them in their local language and translated the responses in French on the survey questionnaires. To assist the farmers in recalling the past production seasons, some key personalized production data were presented during the interview, e.g. cultivated area, yield and bird scaring efforts reported during the annual panel surveys. The analysis of the survey was carried out using descriptive statistics with SPSS for Windows (SPSS, 2007).

## **Results and discussion**

### *Comparison of the models*

The parameter estimates of the models elaborated above are presented in Table 3.<sup>3</sup> Based on the model selection criteria, the CD-I model performs best. The differences between the other models are not that pronounced. Although these criteria indicate that the CD-I model

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<sup>3</sup> For the nonlinear DA models, the presented parameters were considered stable solutions because of the plausible parameters and the fact that no other starting values could be found that resulted in a higher log-likelihood value.

provides the best fit for the data, this does not necessarily imply that it is the best representation of reality.

The parameter estimates for the productive inputs  $\beta_i$ , are very similar across the linear CD models and the nonlinear DA models which suggests that the nonlinear models are fairly robust. Concerning the parameter estimates of the damage abating inputs, the same conclusion can be drawn for the weeding effort parameters  $\gamma_w$  but important differences can be observed for the bird control parameters  $\gamma_b$ .

In the linear CD model, the bird control parameter has a negative sign although it is not significant. Because the coefficients of a Cobb-Douglas production function represent elasticities, this negative sign implies that for each additional unit of bird scaring a farmer deploys, he has a corresponding yield decline. This is a very counterintuitive result.<sup>4</sup> Upon adding pest intensity dummies to the CD model, the  $\gamma_b$  parameter for low pest intensity becomes positive though still insignificant, but the bird control parameters under medium and high pest intensities still display a negative sign however. In the nonlinear DA models the  $\gamma_b$  coefficients do not represent elasticities. Here the implications of a negative sign are that more bird scaring efforts result in a lower value of the DA function which represents the percentage of damage eliminated by the use of the DA inputs. Again, we observe this counterintuitive result in the DA model, although the parameter is not significant. The DA-I model on the other hand features positive parameter estimates for  $\gamma_b$ , which suggests that adding pest intensity dummies efficiently corrects for this specification error.

The damage abatement literature advanced the argument that an asymmetric approach in which DA inputs are incorporated into a DA function is preferred over the traditional

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<sup>4</sup> The only possible interpretation for this result would be that that farmers damage their field substantially whilst scaring birds in their fields (e.g. by walking through it or throwing rocks). These losses due to bird scaring were acknowledged by our surveyed farmers, but were always reported to be of little significance.

symmetric handling of all inputs, the latter leading to biased results. In our analysis, the traditional symmetric CD model also yields counterintuitive parameter estimates for bird scaring efforts, which further argues for the use of an asymmetric specification. However, the asymmetric specification alone does not solve the specification problem. In addition and in conformity with the literature, the inclusion of pest pressure information was found to be essential, because only after their inclusion plausible parameter estimates were obtained. Given these results, the further analysis below will be based on the DA–I model.

< INSERT TABLE 3 HERE >

#### *Production analysis and damage control productivity*

The parameter estimates for land, labor, fertilizer and irrigation costs are statistically significant and positive in the DA–I specification. This means that these inputs significantly and positively contribute to production. The parameter estimates are the elasticities of the respective inputs, which represent the percentage change in yield resulting from a percentage increase in the use of the productive inputs. The parameter estimate for seed is negative (and non significant) however. The underlying principle behind this observation is that the SRV farmers purposely sow too much rice seed as a risk strategy. Firstly, they want a densely planted field that is competitive against weeds. Secondly, the farmers know that part of the seed they sow will be eaten by birds. Thirdly, due to the lack of good quality seed in the SRV, farmers overuse seed as they expect only part of the seed to germinate in their fields. These reasons motivate the farmers to sow at sub-optimal (i.e. exaggerated) planting densities even though this may result in lower yields. In their perceptions this practice acts as a kind of risk premium. In short, the negative sign of the parameter estimate indicates that SRV farmers operate in the declining part of the production function in the production-seed plane.

As already apparent from Table 2, yields were significantly lower in the agricultural season 2006. The negative and significant parameter for the 2006 year dummy confirms this.



Our year-by-year recall questionnaire showed that the SRV farmers strongly feel that increased bird pressure intensity with resulting higher bird damages are the main reason for these lower yields in 2006, combined with other constraints such as the delayed arrival of essential inputs.

Only 8.2% of the farm dummies were significant at the critical 0.05 significance level.<sup>5</sup> This shows that not many farm specific effects were present in the panel. This finding can be explained by the fact that the majority of the SRV farmers are closely following the production practice recommendations advised by the Africa Rice Center and the extension organizations in the SRV.

The DA–I specification further yielded plausible estimates for the parameters of the DA functions. The estimate for the parameter in the weed DA function was significant with a reasonable value. For the bird DA function, three parameter estimates were obtained for three different levels of bird pressure intensity. These three estimates satisfactorily represent the bird control situation as experienced by our surveyed SRV farmers. The value of the parameter decreases from low bird pressure to high bird pressure and even becomes insignificant for the latter, which results in the corresponding DA functions shifting away from the asymptotic unity value. Because the value of the DA function represents the percentage of damage prevented, this shift of the DA function corresponds to a decreased amount of damage prevented under given bird control efforts, i.e. the efficiency of bird control decreases. To visualize the preceding results, Figure 1 was constructed. In this figure, the bird damage function despite control, i.e. one minus the DA–I function, was plotted by

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<sup>5</sup> 10.9% were significant at the 0.10 critical significance level

feeding the farm level bird control data from the dataset and the parameter estimates from Table 3 into the DA-I model.<sup>6</sup>

< INSERT FIGURE 1 HERE >

Firstly, Figure 1 evidences two logical results: (i) bird damage increases as bird pressure rises, which is represented by the upwards shift of the bird damage curves with increasing bird pressure; and (ii) at very low levels of bird control, the proportionate damage increases very fast, which corresponds to the perceptions of our surveyed farmers who stated that potential damage in the absence of bird scaring efforts on average amounts to 83.2%. Furthermore, Figure 1 also indicates the drop in efficiency of bird control according to bird pressure. Under low bird pressure, using an increasing amount of bird control significantly reduces bird damage. At high bird pressure however, the marginal productivity of bird control is closer to zero (or even zero given the insignificant bird DA function parameter estimate), which graphically corresponds to the flattening of the bird damage curves as bird pressure increases. The suggested drop in efficiency also corresponds to the perceptions of our surveyed farmers, who stated that under low bird pressure their traditional bird control techniques (e.g. manual bird scaring, flags and scarecrows) were fairly efficient. Under high bird pressure however, they felt like they were hardly able to control birds effectively and, therefore, explicitly demanded governmental bird population control actions which they perceived as the only effective method under those circumstances. We note however that large scale lethal control measures were found to be ineffective in literature (e.g. see: Ward, 1979). Furthermore, more often than not these measures involve the use of toxic avicides, which entail severe environmental hazards (Mulli   *et al.*, 1999). By contrast, lethal control to

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<sup>6</sup> Note that the parameter estimate for high bird intensity was statistically insignificant at the 0.1 level; hence the slope of the curve should be interpreted with care.

locally reduce pest bird numbers in the vicinity of important cereal production areas to provide temporary relief has been successfully applied (Ward, 1979).

#### *Bird damage estimates*

An overview of the bird damage estimates obtained from our DA production function approach and complementary survey can be found in Table 4. Both the DA approach and survey figures were weighted over production to account for differences in production size.

< INSERT TABLE 4 HERE >

Bird damage despite bird scaring efforts was perceived to be on average 15.2% of potential yield by the SRV farmers during the wet seasons of 2003 to 2007. Using the DA approach, the average damage was estimated at 11.2% of potential yield during the same period. For both estimation approaches, substantial variability between farmers and years was observed however with most weighted standard deviations equaling or even exceeding the means. These large differences can be attributed to the multitude of factors influencing bird damage. Both figures are in accordance with the order of magnitude derived from the literature. Note that all the damage figures reported are only valid for wet season production. Damage during the dry season is expected to be higher according to the literature (Ruelle and Bruggers, 1982). However, only half of our surveyed farmers confirmed this statement.

Where previous studies only covered a single or few agricultural seasons, the present study also provides information on inter-annual variability of bird damage. The data supports the claim of the SRV farmers that bird pressure has increased over the past years. The agricultural season 2006 was clearly the most important bird damage season with an average damage perception of 51.4% and DA estimate of 29.8% of potential yield. The estimates further enable categorizing the agricultural season 2003 as a season with “below average” bird damage and the seasons 2004, 2005 and 2007 as seasons with “average” bird damage.

The difference between both estimation methods suggests that, on average, SRV farmers overestimate bird damage with respect to our DA function estimates by 36%. Upon further inspection of the annual differences, Table 4 indicates that farmers underestimated bird damage during the agricultural seasons 2003–2004 and overestimated bird damage during the agricultural seasons 2005–2007. In relation to the summary statistics of the bird pressure dummy in Table 2, the wet seasons during 2003–2004 were perceived as having no or low bird pressure and the seasons 2005–2007 as having medium or high bird pressure. These figures suggest that farmers have a dichotomous view regarding bird damage: if (i) perceived bird pressure is low, farmers do not perceive this damage as important and tend to underestimate bird damage; but if (ii) perceived bird pressure and the related damage is high, farmers tend to overestimate the true damage caused by birds. These findings indicate that the farmers' bird damage perceptions are related to their attitudes towards risk: farmers are inclined to underestimate bird damage when risk of damage is low and to overestimate bird damage when risk of damage is high. This behavior has been studied in the psychological literature, where the comparison is frequently made between the perceived risk of traveling by air (low probability of an airplane crash but also low controllability) and traveling by car (slightly higher probability of a car crash but higher perceived controllability).

The bird damage estimates obtained in this study were used to extrapolate the total economic cost of bird damage for the entire SRV irrigated rice production for the period 2003–2007. Calculations were based on each season's total production in tons (SAED, 2007), a reference farm price of 150,000 FCFA/tonne (SAED, 2009) and the DA function bird damage estimates.<sup>7</sup> Because total production data were both for wet and dry season

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<sup>7</sup> Bird damage was calculated as:  $\text{actual yield} * (\% \text{ damage} / 1 - \% \text{ damage})$  because the damage estimates were expressed as a function of potential yield but the source production data were actual yield figures. Note that  $\text{actual yield} = \text{potential yield} * (1 - \% \text{ damage})$ .

production, the assumption that bird damage was equal during both production seasons was made. For the period 2003-2007, bird damage on average amounted to 4 billion FCFA (€6.2 million) but was found to be as low as 658 million FCFA (€1.0 million) in 2003 or as high as 9.2 billion FCFA (€14.1 million) in 2006. These figures indicate that granivorous pest birds cause substantial economic losses to irrigated rice production in the SRV, especially in seasons with extreme bird pressure.

Aside from a direct economic impact, birds also have important social consequences for SRV farmers. On the one hand, farmers who scare birds in the field are socially separated from their family for a long time. During the period 2003-2007, our surveyed farmers spent each year on average 26 days per hectare scaring birds in their fields, each day consisting of about 10 hours. On the other hand, 80% of our surveyed farmers mentioned that they deploy their children to scare birds. In one third of these cases (27%), the children missed schooling classes in doing so (28 days on average). We believe however that these figures might even underestimate the impact of birds on schooling rates because if bird pressure is high, most farmers will employ their children anyway because the choice between losing the entire harvest and the children's education will unfortunately be made to the disadvantage of the latter.

## **Conclusions**

Granivorous birds, mainly the Red-billed Quelea, have subsisted on cereal crops in Africa for centuries and have caused substantial damage to agriculture. Limited recent evidence is available however on the impact of birds on cereals in Africa. Yet, before a functional foundation for future control strategies can be designed, accurate estimates of the crop losses inflicted by the pest are needed. This study contributes by presenting and comparing both econometrically estimated and perceived bird damage estimates. These estimates provide timely information for farmers and policy makers in the Senegal River Valley (SRV), who are

currently struggling to implement an ambitious self-sufficiency program. Methodological-wise, a damage abatement (DA) production function analysis was successfully carried out and compared to a classical Cobb-Douglas production function approach. This study points out that the asymmetric DA specification which includes pest pressure information performs better than the traditional symmetric Cobb-Douglas specification, the latter resulting in counterintuitive results.

We use a panel dataset of irrigated rice farmers' production practices in the SRV, surveyed during the wet seasons of the period 2003-2007, and estimate bird damage through a DA production function approach. Using pest intensity dummies, we capture DA processes at different levels of bird pressure. The DA approach enabled us to estimate the average bird damage at 11.2% of the potential rice yield in the SRV during the period 2003-2007. The latter translates into an average annual economic loss of 4 billion FCFA (€6.2 million) for the irrigated rice sector in the SRV. However, losses can amount to 9.2 billion FCFA (€14.1 million) in seasons with extremely high bird pressure, such as the wet season of 2006. To our knowledge, this study is the first to adopt a DA model for bird control and subsequently using it to subtract bird damage estimates.

Using a questionnaire survey complementary to the panel dataset, farmers' bird damage perceptions are estimated to be on average 15.2% of the potential yield. This corresponds with an overestimation of bird damage by 36% compared to the DA function estimates. The differences between both approaches indicate that farmers have a dichotomous view regarding bird damage related to risk perception: at low bird pressure (low perceived risk), they underestimate and at high bird pressure (high perceived risk) they overestimate true bird damage. Future research may further analyze the link between farmers' risk perception, risk attitude and bird control input use and also compare risk attitude with other DA inputs such as weed control. Both the DA approach and the questionnaire survey indicate that at high

bird pressure, the efficiency of traditional bird scaring methods is inadequate. This underlines the importance of local bird population reduction actions by the Senegalese government and investing research in practical, economical and environmentally friendly bird control techniques.

Besides direct economic losses, the impact of birds on SRV irrigated rice production also entails important social consequences with on the one hand farmers who are away from their family for prolonged periods, and on the other hand children constituting an important labor source in conventional bird scarring, the latter being important in view of meeting key education objectives such as universal primary enrollment.

Both estimation techniques in this study are indirect methods to determine bird damage. The farmers' perceptions rely on the experience of the farmers and their ability to correctly assess their production process (i.e. their perceived production function) and extract bird damage from this process. The DA function approach on the other hand was calculated with a formal and well-considered econometric model using panel data, but its major limitation is that it still relies on farmers' annually surveyed perceptions of pest intensities. While acknowledging the limitations of both methods however, this study presents recent estimates of the order of magnitude of bird damage in irrigated rice production in the SRV. Note however that bird damage is seldom uniformly distributed among farmers or systematic, hence the true economic and social impact at farm level goes well beyond overall averages.

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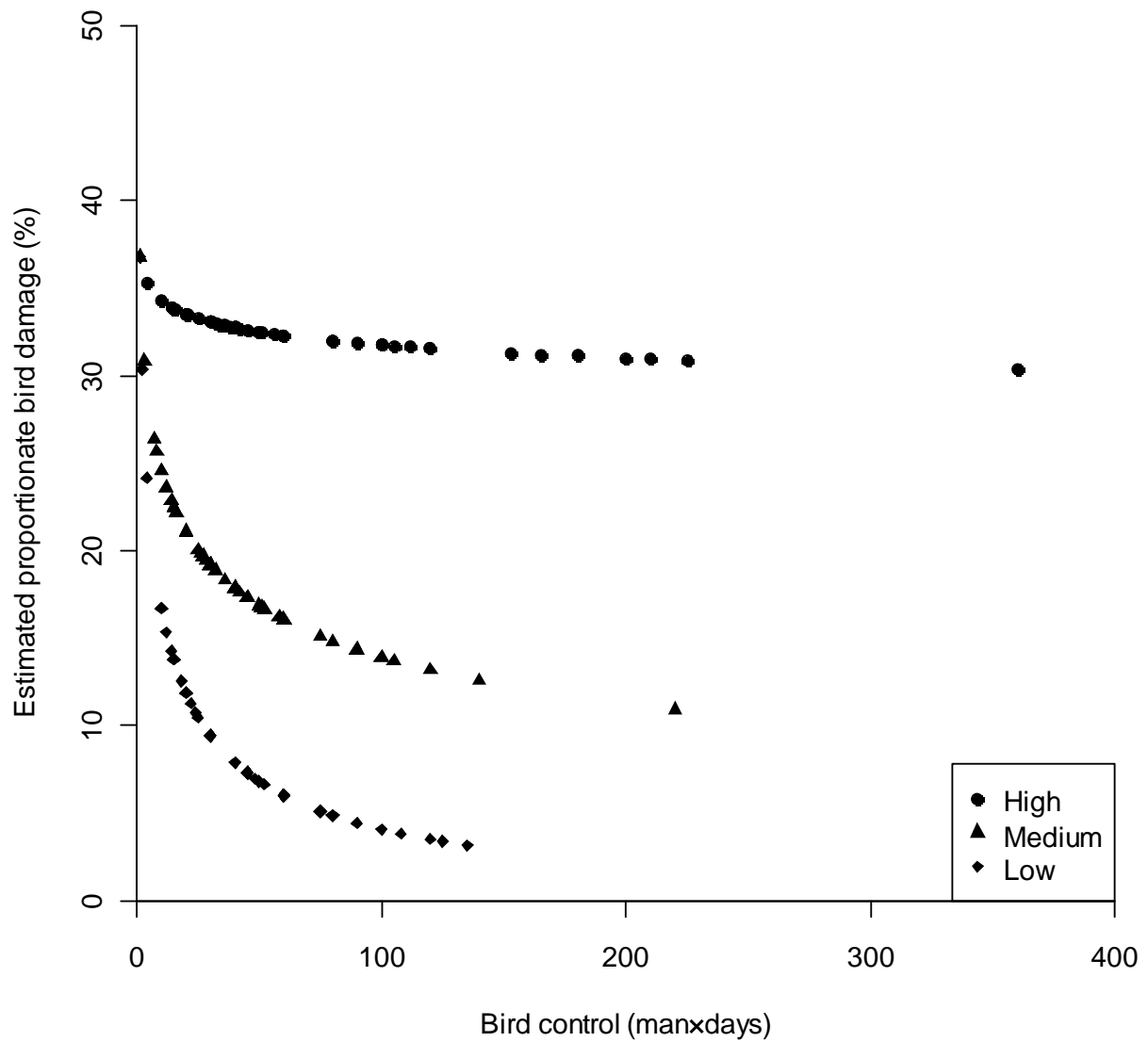


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**Figure 1: Representation of the bird damage function despite control under different bird pressures in irrigated rice production in the SRV**

**Table 1: Overview of studies reporting bird damage estimates on cereal crops in Africa**

| Region           | Year (period)     | Crop                               | Estimation of losses  | Estimation method (sample size <sup>a</sup> )       | Major species  | Source   | Reference   |
|------------------|-------------------|------------------------------------|---|---|--|--|---|
| Africa, Sahel    | n.a. <sup>b</sup> | n.a.                               | 5% of national production (but up to 100% locally)  | n.a.  | Red-billed Quelea  | Book chapter   | FAO (2001)  |
| Africa, Savannah | n.a.              | n.a.                               | 1 % of production   | n.a.  | Red-billed Quelea  | Book chapter   | FAO (2001)  |
| Chad             | 1975-1977         | Rice                               | “Damage varied from 13% to 26% when harvest overlapped with birds’ arrival”   | Quantitative estimation (10 plots – 2,000 panicles) | Red-billed Quelea  | Journal article (Journal of Applied Ecology)                                     | Elliott (1979)  |
| Ethiopia         | 1977              | Sorghum                            | \$0.5 – 0.7 million lost to birds   | Visual estimation (5 sites – 1,000 panicles)        | Red-billed Quelea  | Conference proceeding  | Jaegar and Erickson (1980)  |
| Kenya            | 1952              | Wheat, Rice, Millet, Sorghum       | \$0.7 million loss; 100,000 bags  | n.a.  | Red-billed Quelea, “Doves”, “Weavers”, “Starlings”                 | Report   | De Grazio (1973); De Grazio and Dehaven (1974); Pearson (1967) cited by De Grazio (1978)        |
| Mali             | 1983-1986         | Rice                               | “Damages are very variable among years (from 0.76 to 14 % of the harvest, by mean), but they are not uniformly distributed, some fields being very heavily destroyed, when other are untouched” | Visual estimation (80 plots – 10,000 panicles)      | “Ducks”, “Ruffs”   | Journal article (Journal d’agriculture traditionnelle et de botanique appliquée) | Treca (1987)  |
| Morocco          | 2001-2002         | Rice                               | 22% of production   | Survey (n = 280)                                    | “Grain eating”   | Report   | Sidibé <i>et al.</i> (2003)   |
|                  | n.a.              | Wheat, Rice                        | Wheat loss most severe ; \$4.0 million loss   | n.a.  | House Sparrow, Spanish Sparrow                                     | Report   | De Grazio <i>et al.</i> (1971) cited by De Grazio (1978)  |
| Nigeria          | n.a.              | Rice, Wheat, Millet, Sorghum, Corn | \$2.8 million/year loss in one province   | n.a.  | Red-billed Quelea, Golden Sparrow, “Starlings”, “Doves”, “Weavers” | Report   | De Grazio <i>et al.</i> (1971); Pearson (1967); Ward and Jones (1977) cited by De Grazio (1978) |
| Senegal, country | 1976-1977         | Cereals                            | 5% of total cereal production (the equivalent of \$4-5 million)   | Quantitative estimation (375 plots)                 | “Weavers”, Red-billed Quelea, Golden Sparrow                       | Journal article (Protection Ecology)   | Bruggers and Ruelle (1981)  |
| Senegal, SRV     | 1976-1977         | Rice                               | 6.8% of production  | Quantitative estimation (31 plots – 9,500 panicles) | “Weavers”, Red-billed Quelea, Golden Sparrow                       | Journal article (Protection Ecology)   | Bruggers and Ruelle (1981)  |
|                  | 1989              | Rice                               | 6 out of 10 parcels were damaged more by birds than protected ones  | Quantitative estimation (10 plots – 200 panicles)   | “Water birds”  | Report   | Treca (1989)  |
|                  | 2008              | Cereals                            | If birds are numerous, they can consume around 15% of regional harvest  | n.a.  | Red-billed Quelea  | Personal communication   | Ibrahima Diop, DPV Saint-Louis  |
| South Africa     | 1953              | Cereals                            | \$1.4 million loss of sorghum   | n.a.  | Red-billed Quelea  | Conference proceeding  | Hey (1964); Pearson (1967) cited by De Grazio (1978)  |
| Somalia          | 1975-1979         | Rice, Sorghum, Maize               | Damage averaged between 1% – 78% depending on crop and field location   | Discussions – Sampling                              | Village Weaver, Golden Palm Weaver, Chestnut Weaver, Red Bishop    | Conference proceeding  | Bruggers (1980)   |
|                  | 1975-1981         | Maize, Rice, Sorghum               | 27% damage on non-private farms and 5.5% damage on private farms  | n.a.  | Red-billed Quelea, “Sparrows”, “Bishops”, “Weavers”                | Conference proceeding  | Ruelle and Bruggers (1982)  |
| Sudan            | n.a.              | Sorghum                            | \$0.9 million loss annually   | n.a.  | Red-billed Quelea  | Report   | Schmutterer (1969) cited by De Grazio (1978)  |

Notes:

<sup>a</sup> # panicles always refers to the total sample size, not # panicles/ plot

<sup>b</sup> n.a.= not available

**Table 2: Descriptive statistics of panel dataset of irrigated rice farmers in the Senegal River Valley, 2003-2007**

|                                   |          | Agricultural season |                   |                   |                  |                 | Total Average    |
|-----------------------------------|----------|---------------------|-------------------|-------------------|------------------|-----------------|------------------|
|                                   |          | 2003                | 2004              | 2005              | 2006             | 2007            |                  |
| Yield (tons)                      |          | 8.15 (9.95)         | 9.20 (11.37)      | 8.48 (9.09)       | 4.74 (5.25)      | 8.29 (11.12)    | 7.79 (9.71)      |
| Land (ha)                         |          | 1.49 (1.94)         | 1.55 (1.91)       | 1.58 (1.94)       | 1.62 (1.95)      | 1.65 (1.93)     | 1.58 (1.93)      |
| Seed (kg)                         |          | 199.15 (267.81)     | 197.52 (249.61)   | 200.94 (266.34)   | 211.43 (281.21)  | 215.38 (253.08) | 204.71 (262.42)  |
| Labor (man×days)                  |          | 77.74 (47.45)       | 82.90 (58.15)     | 86.50 (63.82)     | 75.93 (38.33)    | 97.07 (58.33)   | 84.32 (54.69)    |
| Fertilizer (kg)                   |          | 497.65 (686.09)     | 587.73 (725.34)   | 561.98 (676.44)   | 551.45 (715.38)  | 496.36 (671.92) | 539.63 (693.29)  |
| Irrigation costs (FCFA)           |          | 100,568 (132,190)   | 101,212 (129,198) | 100,575 (120,769) | 96,800 (114,871) | 88,037 (94,086) | 97,456 (118,516) |
| Weeding efforts (FCFA)            |          | 34,627 (33,594)     | 44,976 (40,552)   | 59,783 (108,551)  | 49,502 (58,396)  | 44,239 (57,793) | 46,802 (66,153)  |
| Bird control (man×days)           |          | 5.68 (12.00)        | 32.71 (41.45)     | 37.67 (30.17)     | 56.51 (42.07)    | 45.94 (48.77)   | 36.28 (41.11)    |
| Bird pressure intensity dummy (%) | High     | 0.0                 | 6.9               | 11.6              | 76.1             | 32.6            | 26.0             |
|                                   | Medium   | 10.7                | 26.4              | 40.0              | 16.3             | 22.8            | 23.6             |
|                                   | Low      | 17.8                | 49.4              | 34.7              | 3.3              | 34.8            | 28.0             |
|                                   | No birds | 71.4                | 17.2              | 13.7              | 4.3              | 9.8             | 22.4             |
| Sample size                       |          | 92                  | 96                | 98                | 93               | 94              | 473              |

Notes: Standard deviations are shown between brackets. Fixed exchange rate: €1 = 656 FCFA

**Table 3: Estimated production function parameters**

| Parameter           | Description      | Model             |                   |                               |                   |
|---------------------|------------------|-------------------|-------------------|-------------------------------|-------------------|
|                     |                  | Cobb–Douglas      |                   | Cobb–Douglas with DA function |                   |
|                     |                  | CD                | CD–I              | DA                            | DA–I              |
| $\alpha$            | Intercept        | –0.322 (1.716)    | –1.622 (1.684)    | 0.088 (1.716)                 | –1.304 (1.747)    |
| $\beta_1$           | Land             | 0.862 (0.206)***  | 0.724 (0.202)***  | 0.828 (0.210)***              | 0.711 (0.213)***  |
| $\beta_2$           | Seed             | –0.299 (0.153)*   | –0.289 (0.149)*   | –0.278 (0.156)*               | –0.255 (0.156)    |
| $\beta_3$           | Labor            | 0.129 (0.049)***  | 0.107 (0.047)**   | 0.132 (0.049)***              | 0.102 (0.049)**   |
| $\beta_4$           | Fertilizer       | 0.150 (0.075)**   | 0.161 (0.073)**   | 0.161 (0.074)**               | 0.158 (0.074)**   |
| $\beta_5$           | Irrigation costs | 0.110 (0.132)     | 0.220 (0.130)*    | 0.144 (0.134)                 | 0.245 (0.137)*    |
| $\gamma_w$          | Weeding efforts  | 0.050 (0.028)*    | 0.057 (0.027)**   | 0.838 (0.391)**               | 0.723 (0.318)**   |
| $\gamma_b$          | Bird Control     | –0.021 (0.017)    |                   | –0.033 (0.027)                |                   |
| $\gamma_b^L$        | Bird:IntensityL  |                   | 0.013 (0.019)     |                               | 0.253 (0.093)***  |
| $\gamma_b^M$        | Bird:IntensityM  |                   | –0.020 (0.018)    |                               | 0.148 (0.050)***  |
| $\gamma_b^H$        | Bird:IntensityH  |                   | –0.071 (0.019)*** |                               | 0.030 (0.037)     |
| $t_1$               | Year (2004)      | 0.075 (0.066)     | 0.050 (0.064)     | 0.082 (0.066)1                | 0.143 (0.065)**   |
| $t_2$               | Year (2005)      | 0.009 (0.071)     | –0.011 (0.069)    | 0.019 (0.071)                 | 0.064 (0.070)     |
| $t_3$               | Year (2006)      | –0.502 (0.076)*** | –0.346 (0.081)*** | –0.496 (0.076)***             | –0.283 (0.084)*** |
| $t_4$               | Year (2007)      | –0.079 (0.075)    | –0.036 (0.074)    | –0.076 (0.075)                | 0.024 (0.076)     |
| Adj. R <sup>2</sup> |                  | 0.852             | 0.862             | n.a.                          | n.a.              |
| Log likelihood      |                  | –69.474           | –54.511           | –69.209                       | –69.314           |
| AIC                 |                  | 384.948           | 359.021           | 384.418                       | 388.629           |
| Schwartz BIC        |                  | 876.205           | 858.266           | 875.675                       | 887.874           |

Notes: Std. errors are shown between brackets. Farm dummies  $f_k$  were omitted for brevity. Significance codes: 0.01 ‘\*\*\*’ 0.05 ‘\*\*’ 0.10 ‘\*’. n.a. = not applicable



**Table 4: Estimated bird damage and economic loss in irrigated rice in the SRV, 2003-2007**

|                         |   | Agricultural season |            |             |             |             | Overall average <sup>b</sup> |
|-------------------------|---|---------------------|------------|-------------|-------------|-------------|------------------------------|
|                         |   | 2003                | 2004       | 2005        | 2006        | 2007        |                              |
| Average bird damage     | Farmers' perceptions (% <sup>a</sup> )  | 0.6 (3.2)           | 6.0 (8.8)  | 10.7 (13.5) | 51.4 (35.1) | 12.1 (15.7) | 15.2 (25.6)                  |
|                         | DA function estimates (% <sup>a</sup> ) | 2.8 (7.2)           | 8.3 (10.1) | 9.7 (9.8)   | 29.8 (6.7)  | 11.2 (10.3) | 11.2 (12.2)                  |
| Estimated economic loss | 10 <sup>9</sup> FCFA <sup>c</sup>       | 0.7                 | 2.7        | 3.0         | 9.2         | 4.7         | 4.0                          |
|                         | 10 <sup>6</sup> €                       | 1.0                 | 4.1        | 4.5         | 14.1        | 7.1         | 6.2                          |

*Notes:*

<sup>a</sup> % Of potential yield, weighted over production, weighted standard deviations are shown between brackets

<sup>b</sup> Total average over entire period, weighted over production

<sup>c</sup> €1 = 656 FCFA